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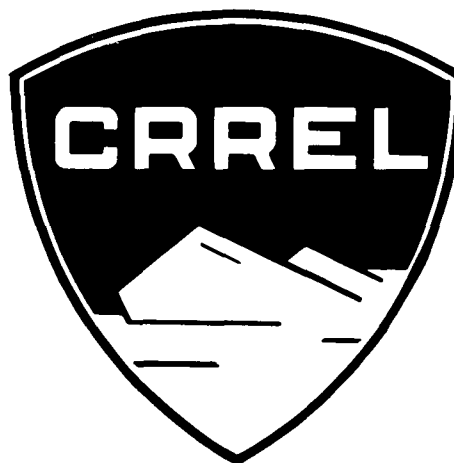
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Research Report 124

MARCH, 1963

**An Investigation of
Specialized Whiteout
Seeding Procedures**

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U. S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

AD U. S. Army Cold Regions Research and Engineering Laboratory, Army Materiel Command, Hanover, N. H. AN INVESTIGATION OF SPECIALIZED WHITEOUT SEEDING PROCEDURES - Thomas R. Mee, Jr. and W. J. Eadie Research Report 124, March 1963, 11p-illus-app. DA Proj 8X99-27-001-03, Contract DA-11-190-ENG-100. UNCLASSIFIED	Accession No	UNCLASSIFIED 1. Whiteout--Counter-measures I. Mee, Thomas R. II. Eadie, W. J. III. Cornell Aeronautical Laboratory IV. U. S. Army Cold Regions Research and Engineering Laboratory Contract DA-11-190-ENG-100	AD U. S. Army Cold Regions Research and Engineering Laboratory, Army Materiel Command, Hanover, N. H. AN INVESTIGATION OF SPECIALIZED WHITEOUT SEEDING PROCEDURES - Thomas R. Mee, Jr. and W. J. Eadie Research Report 124, March 1963, 11p-illus-app. DA Proj 8X99-27-001-03, Contract DA-11-190-ENG-100. UNCLASSIFIED	Accession No	UNCLASSIFIED 1. Whiteout--Counter-measures I. Mee, Thomas R. II. Eadie, W. J. III. Cornell Aeronautical Laboratory IV. U. S. Army Cold Regions Research and Engineering Laboratory Contract DA-11-190-ENG-100
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by T. R. Mee, Jr. and W. J. Eadie

U. S. ARMY COLD REGIONS RESEARCH
AND ENGINEERING LABORATORY
Hanover, New Hampshire

PREFACE


This report on Phase II of Project WHITEOUT was prepared by Cornell Aeronautical Laboratory, Inc., of Cornell University under Contract DA-11-190-ENG-100 with the U. S. Army Cold Regions Research and Engineering Laboratory (USA CRREL).

The research for this report was performed for USA CRREL's Research Division under the general supervision of Dr. R. W. Gerdel, chief, Environmental Research Branch.

Project WHITEOUT is a research program aimed at understanding and developing cloud-seeding methods for modifying arctic whiteouts. During Phase I of this project, an experimental program was conducted at Camp Fistclench in northern Greenland to determine the extent to which whiteouts could be modified. Whiteouts caused by supercooled clouds were successfully dissipated by seeding with dry ice dispensed from an aircraft and with dry ice in small baskets suspended from a blimp tether. Line openings up to 2.5 miles were produced in the cloud cover causing the whiteout. Results of these experiments are reported in USA CRREL Technical Report 84.

Phase II of the project has been devoted to developing specialized whiteout-dissipation procedures and, in that context, to developing a better understanding of the physics of seeding clouds with dry ice. All experiments during Phase II were conducted within the laboratory.

This report has been reviewed and approved for publication by the Commander, U. S. Army Materiel Command.


W. L. NUNGESSER
Colonel, Corps of Engineers
Commanding Officer
USA CRREL

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SUMMARY

Investigations were carried out to develop field techniques and equipment that could be used by U. S. Army personnel to dissipate whiteouts. Several types of seeding vehicles were examined, including drone aircraft, mortar shells, rockets and regular aircraft. With the objective of improving efficiency of the dry-ice-seeding process, an investigation was conducted to delineate the various physical processes that occur during seeding.

Measurements were made of the distance a dry-ice pellet falls before subliming completely, and the number of ice crystals produced by a dry-ice pellet was determined, both as a function of pellet size and ambient temperature. It was discovered that the ice-crystal productivity of dry-ice pellets falling at their terminal velocities decreases sharply at temperatures warmer than about -5°C , whereas the ice-crystal productivity of slowly moving pellets is not greatly affected.

A device for converting liquid CO_2 into dry-ice pellets was conceived, and the concept was employed in the development of an emergency-seeding device for use in aircraft. The device would be particularly valuable during unexpected encounters with whiteouts in remote regions.

AN INVESTIGATION OF SPECIALIZED WHITEOUT SEEDING PROCEDURES

by

Thomas R. Mee, Jr., and W. J. Eadie

INTRODUCTION

The arctic whiteout is an atmospheric phenomenon that arises from the optical blending of snow-covered terrain with a meteorological obscuration or low cloud overcast. Because the effect can result in an individual's loss of orientation and depth perception, it constitutes a serious hazard to ground and air operations in the Arctic.

Experimental investigations conducted during Cornell Aeronautical Laboratory's Project WHITEOUT (Contract DA-11-190-ENG-100) have proven the feasibility of dispersing the supercooled cloud-type whiteouts that occur over the Greenland Ice Cap. These experiments also demonstrated the need for specialized equipment for dispensing cloud-nucleating agents. The development of such equipment was initiated during FY 1962, and is summarized in this report.

For the first experiments, steel cylinders of liquid CO₂ were shipped to Greenland to provide raw material for making dry ice, but it soon became apparent that the cumbersome nature of the cylinders would present a severe logistics problem for any extensive field operation. For that reason, and because seeding vehicles of limited payload capability were being contemplated, a fundamental investigation of the seeding process aimed at improving the efficiency of conventional dry-ice seeding techniques was initiated. Hence, this report is concerned with both the development of equipment and a fundamental study of physical processes.

IMPROVING THE EFFICIENCY OF DRY-ICE SEEDING

Seeding experiments conducted in Greenland during the summer of 1960 led to the conclusion that a minimum of 5 lb of dry ice per mile was necessary to effect significant whiteout suppression. In those experiments 1-lb cakes of dry ice were fed at the proper rate into a small commercial ice crusher* which produced the pellets and dispensed them into the cloud. The technique has been used successfully by other investigations for seeding stratus clouds with similar results. Recent laboratory experiments conducted on this project indicate the efficiency of dry-ice seeding can be significantly increased by proper choice of dry-ice pellet size and of dispensing technique. Results of these experiments are summarized below and are discussed in detail in Appendices A and B.

The size distribution of dry-ice pellets produced by the Hail Queen crusher is shown in Figure 1.

From these data we have drawn the following conclusions:

1. About 15% of the dry ice sublimed before leaving the ice crusher, therefore was wasted.
2. About 22% of the total mass of dry ice was crushed into particles of diameter equal to or smaller than 0.1 in. Appendix B shows that all particles in that size range will sublime before falling 100 ft when dropped from a moving aircraft. Since the seeding aircraft in the Greenland experiments normally flew 100 ft or more above the cloud, 22% of the dry ice fed to the crusher did not participate in the nucleation process.

*Hail Queen ice cube dicer, manufactured by Clawson Machine Co., Inc., Flagtown, New Jersey.

WHITEOUT SEEDING PROCEDURES

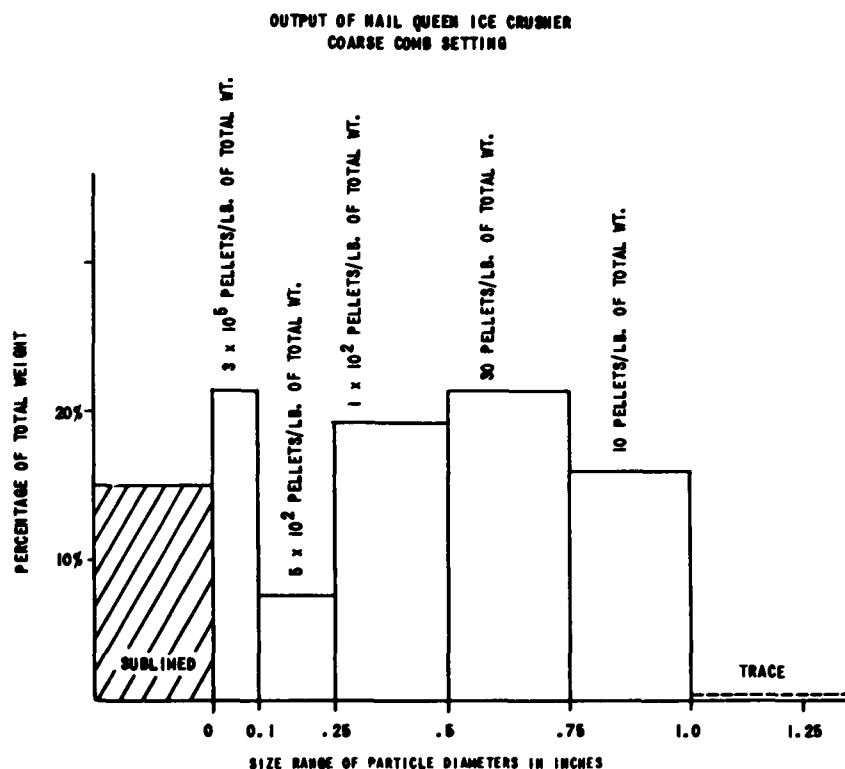


Figure 1. Distribution of sizes of crushed dry ice.

3. About 56% by weight of the dry-ice pellets fed to the crusher had diameters in excess of 0.25 in. If the cloud is 1000 ft thick (a typical value) these particles will fall through it before subliming completely. In fact, only 20% of the total mass of particles having diameters greater than 0.25 in. will sublime in the 1000-ft-thick cloud, indicating that these particles are only 20% efficient. Thus, an additional 45% (80% of 56%) of the dry ice used was ineffective.

In summary, it may be concluded that of the 5 lb of dry ice per mile used in the Greenland experiments, only about 20% actually participated in the nucleating process when dealing with typical 1000-ft-thick clouds. Obviously, these dry-ice losses can be significantly reduced by proper selection of pellet size.

Since it is not possible to determine the thickness of clouds that will be encountered in an unexpected whiteout, the choice of dry-ice pellet size to be used must be governed by the maximum cloud thickness that can produce a whiteout and can be effectively dissipated. Thus, pellets which fall about 3000 ft before subliming completely are required. Such pellets would weigh approximately 0.25 g and would be roughly 50% efficient for 1000-ft-thick clouds and 80% efficient for 2000-ft-thick clouds. A seeding rate of 2.2 lb per mile, which includes an adequate safety factor, would cover all situations that can be effectively modified.

A primary objective of the investigation of the seeding properties of dry ice was to explain the apparent discrepancies between the estimated number of ice crystals produced in the Greenland experiments and the number which, according to published investigations, should have been produced. Calculations based on Langmuir's figure of 10^{17} ice embryos produced per g of dry ice (Langmuir, 1948) predict that 10^4 ice embryos per cm^3 of cloud dissipated should have been produced.

A typical liquid-water content for a whiteout-producing cloud would be about 0.2 g/m^3 of $2 \times 10^{-3} \text{ g/cm}^3$. This would provide only about 10^{-11} g of water to each embryo, a factor of 10^7 too small if the embryo were to grow to a typical snowflake size. Therefore, the question naturally arose as to how one could explain the large difference between the number of embryos supposedly produced and a reasonable estimate for number of snowflakes. An application of the results of recent laboratory experiments (discussed in Appendix A) indicates that actually a much smaller number of embryos were produced than is indicated by an application of Langmuir's figures.

Experiments indicated that dry ice will produce about 10^{10} ice embryos per g of dry ice dissipated within the cloud. That this number is reasonable for field use may be illustrated by an examination of the results of the 15 July 1960 experiment in Greenland. On the basis of the efficiency estimate, it appears that about 400 g of dry ice per mile sublimed completely within the 1000-ft-thick cloud that was seeded. Each seeded track was 3 miles long; thus about 10^{13} ice embryos were produced. The 1200 g of dry ice were responsible for clearing a cloud volume measuring approximately $6000 \times 4000 \times 300 \text{ m}$ thick, equal to $7 \times 10^{15} \text{ cm}^3$ of cloud volume. Therefore, if it is assumed that all of the embryos produced grew into snowflakes that were precipitated in the cleared area, there would have been one snowflake produced per 600 cm^3 of cloud volume cleared. This would mean that about 50 snowflakes fell on each cm^2 of ground area. Since a typical snowflake weighs about 0.1 mg (Mason, 1957, p. 171), 0.05 mm of equivalent rain would have fallen, which can be explained by the precipitation of the entire cloud if it had a typical liquid-water content of about 0.2 g/m^3 . All of these numbers seem reasonable.

Experiments to determine the number of ice embryos produced by a given amount of dry ice were conducted in the laboratory (see Appendix A) by exposing a pellet of dry ice to a supercooled cloud for a known amount of time and then counting the resulting ice crystals. It was shown that there is a critical temperature (-5°C) above which a pellet of dry ice moving at terminal velocity through a cloud will not produce a significant number of ice crystals and, in fact, may not produce enough to be effective in cloud seeding.

It was hypothesized that there is a critical time period associated with the growth of the embryonic ice crystals that are initially formed in the wake of a falling dry-ice pellet. These ice embryos must grow beyond a certain critical size if they are to exist as snow-crystal nuclei at ambient temperatures. The growth must take place while the ice embryos are still within the low-temperature, supersaturated field produced by the dry ice, and the critical size is determined principally by the ambient temperature within the supercooled cloud being seeded. The length of time that the ice embryos will remain in the low-temperature field in the pellet's wake is strongly influenced by the velocity of the air relative to the dry-ice pellets. Therefore, if dry ice is falling at its terminal velocity, and if ambient temperatures are only a degree or so below freezing (and critical embryo sizes therefore large), it is logical to question whether or not the minimum growth time for ice embryo formation will be available during residence of the embryo within the cold wake of the pellet.

This hypothesis was checked experimentally. The ice crystal productivity of dry-ice pellets moving at terminal velocity was found to decrease sharply when cloud temperatures were warmer than about -5°C . However, if the dry-ice pellets were held relatively stationary within the cloud, high ice-crystal-production rates were maintained to the maximum temperatures tested, about -0.5°C . Thus, it can be expected that the efficiency of the conventional dry-ice seeding method (of dropping pellets through a cloud) will decrease sharply when cloud temperature increases beyond -5°C . This, indeed, is often observed. To increase the efficiency of seeding at the warmer temperatures, seeding techniques must be developed which do not permit such rapid motion of the CO_2 pellets in the cloud. The tethered balloon method used in the 1960 Greenland experiments is one such technique. Such experiments should be repeated in clouds having temperatures between 0°C and -5°C to verify the results of laboratory experiments for field use.

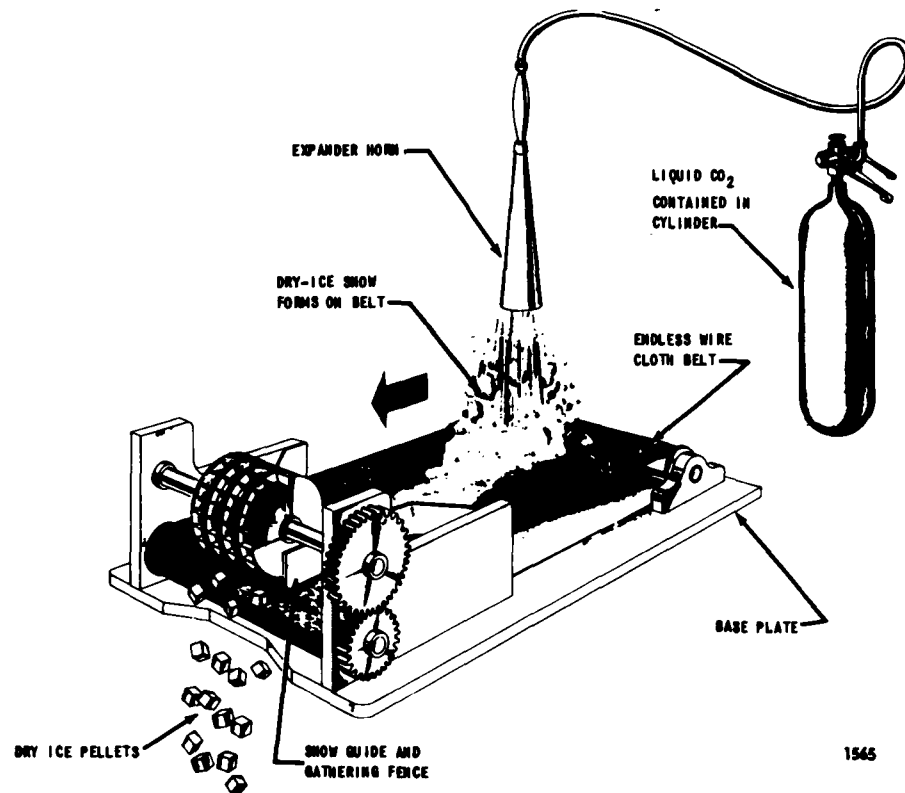


Figure 2. Schematic diagram of the feasibility study model, liquid-to-solid- CO_2 pellet maker.

DEVICE FOR MAKING DRY-ICE PELLETS

Rather than carry large quantities of dry ice* for emergency use during whiteouts, it is much more feasible for an aircraft to have a pellet-making capability, provided of course that the required equipment is light, compact, and relatively efficient. With these features fixed as requirements, a laboratory experimental model of a device that converts liquid CO_2 directly into dry-ice pellets of a specified size and density was designed and fabricated (Figs. 2 and 3).

Briefly, the dry-ice pellet maker operates as follows. Upon the release of liquid CO_2 through an expansion horn, sufficient cooling occurs to cause some of the CO_2 to solidify into "snow." The snow is collected on a wire-screen conveyor belt and fed first under a compressing roller and then onto a multicelled cubing cylinder that further compresses the snow into roughly cubical pellets. The remainder of the CO_2 evaporates or sublimates and passes through the wire-screen conveyor belt, thus does not form a back-wash that would scatter the snow. After the operations of compressing and cubing, the dry-ice pellets are discharged from their cells. Laboratory experience with the device pictured in Figure 3 indicated that design improvements were necessary in order to eliminate a tendency of the pellets to stick to the "cells" in which they are formed. As of this writing a cam-operated-piston mechanism is being constructed for the ejection

* Dry ice cannot be stored for long periods because of sublimation.

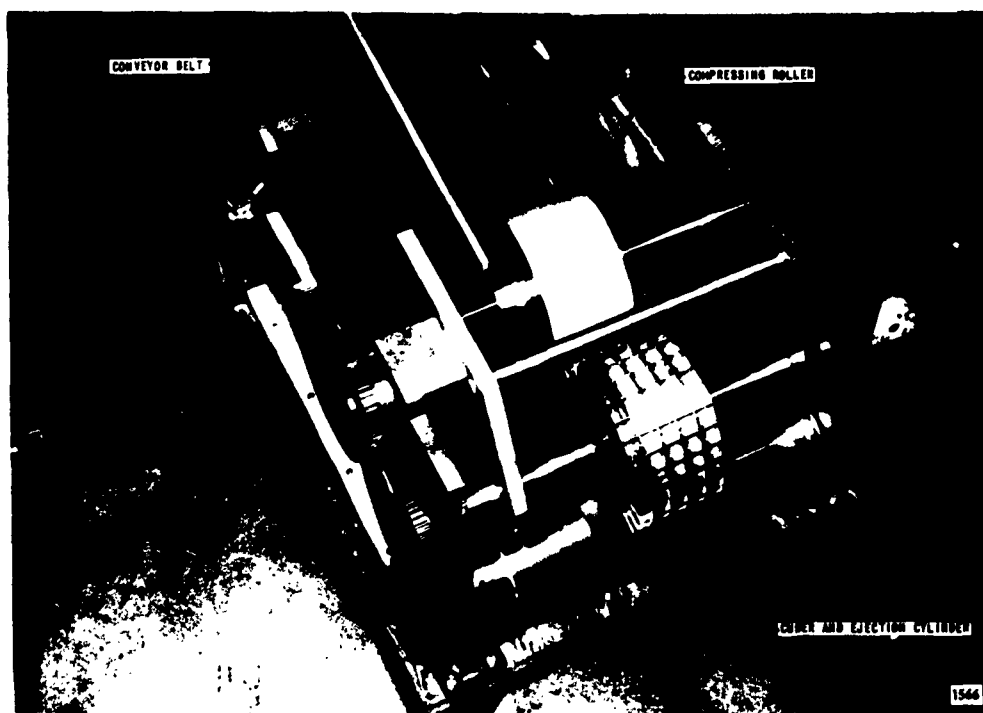


Figure 3. Pellet maker.

of pellets. The ejector cylinder will appear similar to the device shown in Figure 3, but the internally contained pistons (inside the cylinder) will thrust out through each row of cells, thus forcefully discharging the pellets.

Preliminary experiments have shown that pellets formed in that manner would have a density of about 0.75 g/cm^3 , which is about the same as that of the dry ice used in the Greenland seeding experiments. Experiments also indicated that under typical seeding conditions, a liquid-to-solid conversion efficiency of between 35 and 40% can be expected, as compared to the 15 to 20% conversion efficiency obtained with the commercial dry-ice-making machine used during the 1960 Greenland experiments.

The amount of "snow" that can be obtained by expanding liquid CO_2 from standard tank pressure to atmospheric pressure is a function of the starting temperature of the liquid CO_2 . Figure 4 shows tank pressure as a function of temperature, whereas Figure 5 shows the maximum amount of CO_2 snow that can be obtained by an expansion of the CO_2 when the tank is precooled to a given temperature.

Three points on the conversion-efficiency curve were checked experimentally. Two points were based on CO_2 bottles that were stored indoors, and one point was based on a CO_2 bottle that had been kept outdoors in anticipation of a cold day. The outdoor bottle was emptied when it was at -8°C (a typical whiteout temperature), and a conversion efficiency of 38% was measured. The other two bottles produced less than 25% efficiency. From these measurements it is obvious that, for an airborne version of the pellet maker, the CO_2 storage bottles should be maintained at ambient air temperatures and not be kept in a heated cabin.

The work completed thus far has shown without a doubt that a workable, emergency-seeding device can be made. Preliminary results indicate that such a device should

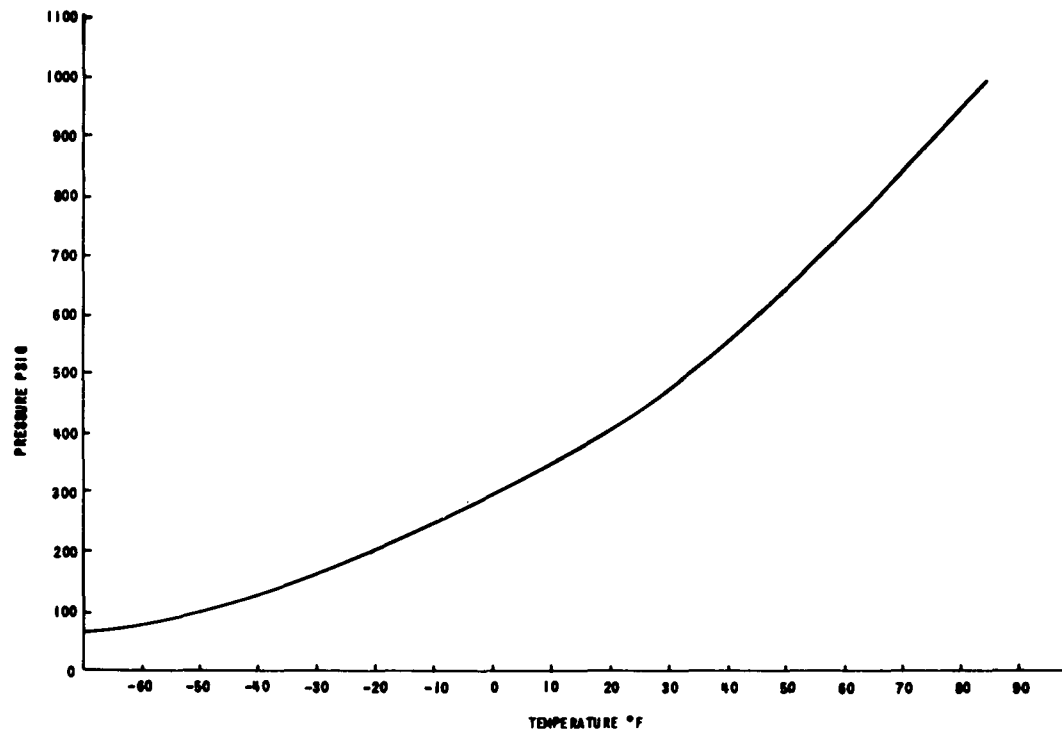


Figure 4. Variation of pressure in a container of liquid CO_2 .

produce dry ice twice as efficiently as the commercially made dry-ice makers that were used in the Greenland experiments. Of more importance is the fact that all pellets will be of the proper size, therefore making it necessary to use only one-fifth to one-half as much dry ice to effectively seed a cloud. For these reasons it seems important that pellet-making devices also be used to produce dry ice for operations where whiteouts are to be seeded from the ground. A standard, liquid- CO_2 container weighs more than twice as much as the CO_2 that it contains. Therefore, the logistical problem of transporting CO_2 to remote areas such as the Greenland ice cap can be considerably lessened by having a more efficient dry-ice making process. In fact, only one-tenth to one-fourth as many tanks of liquid CO_2 will be needed if pellet makers are used to produce the dry ice necessary for whiteout seeding.

It should be noted that Allied Research Associates, Boston, Massachusetts, through the sponsorship of Air Force Cambridge Research Laboratory, is developing a dry-ice pellet maker that will eventually be marketed commercially. ARA was contacted to ascertain whether their device would be suitable for the use of Project WHITEOUT and whether one would be available for purchase in the near future. ARA was unable to indicate a price or an expected delivery date.

The development model of their pellet maker was reported to weigh about 600 lb, exclusive of the weight of the CO_2 and storage tanks. However, it is intended to use this device from large cargo planes where its weight is not an important factor.

Development of the CAL lightweight pellet-making device will satisfy specific U. S. Army needs and will serve as a flexible "tool" in extended laboratory effort. The development of this device to a practical stage is one objective of an immediate future program.

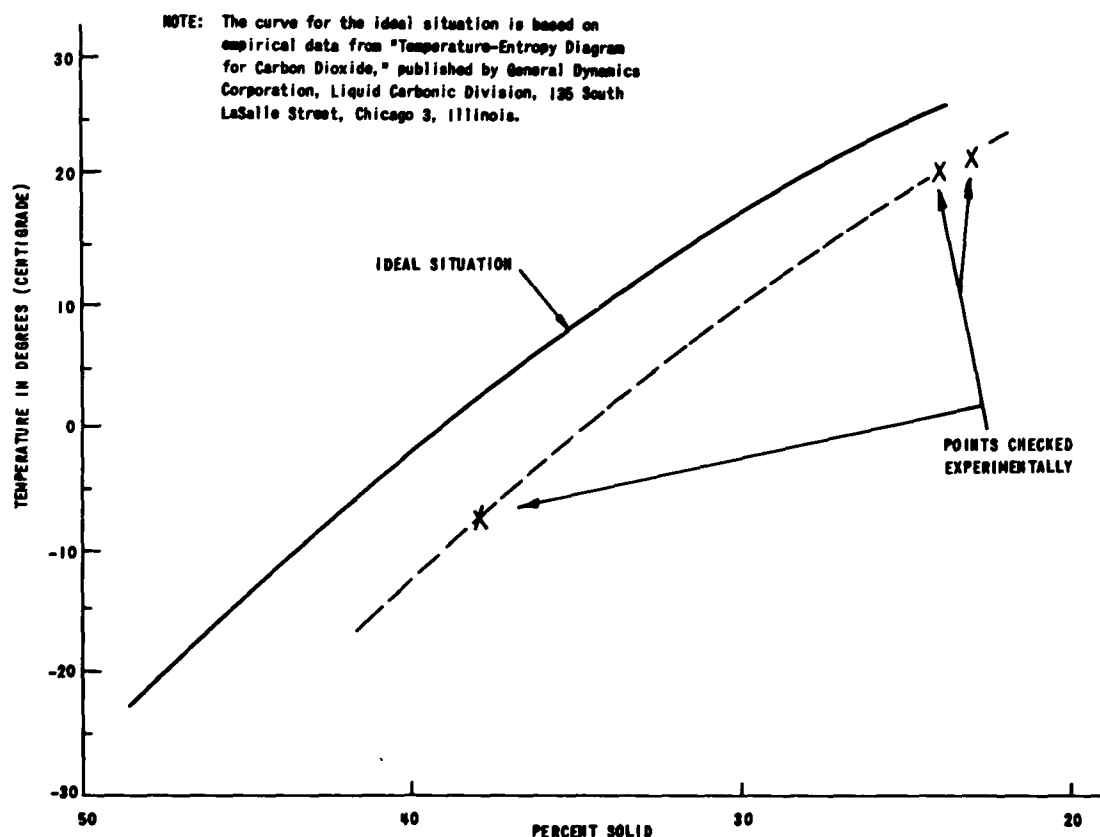


Figure 5. Percentage solid CO₂ obtained when expanding from standard tank pressures.

DRONE INVESTIGATIONS

The seeding experiments conducted in Greenland in the summer of 1960 gave ample evidence that flying in even moderate whiteout situations is hazardous; for safety reasons, small manned aircraft of the type employed by the U. S. Army should be used only in less-hazardous whiteout conditions. For this reason it was felt that drones, which could be employed regardless of the severity of the whiteout and, therefore, perform seeding maneuvers not feasible with manned aircraft, might be excellent vehicles for cloud-modification work.

A survey of all potentially available drones was made to see which might be most suitable for seeding whiteouts. It was concluded that either AN/USD-1 or AN/USD-2 drones would be useful. The AN/USD-2 (XAE-3) was judged best suited for the purpose, but it would not be readily available for several years. Therefore, subsequent investigations were concentrated on the USD-1.

The USD-1, shown in Figure 6, was initially thought to be only marginally useful because of its limited payload capability; however, subsequent investigations showed that its payload, normally listed as 65 lb, could be increased to 90 lb by replacing the two wingtip, radar-reflector pods with a DPN-62, X-band radar beacon. Of the 90-lb payload, 65 lb could be jettisoned in the form of seeding material. (The cargo compartment is located forward of the center of gravity and a greater change in payload would cause the drone to become unstable in flight.) A dry-ice load of 65 lb is enough to seed

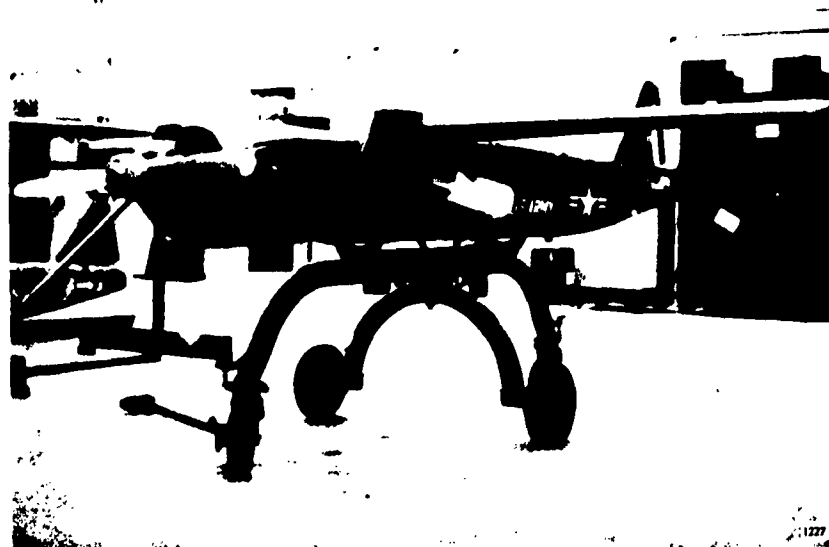


Figure 6. USD-1 drone.

more than 20 miles of track at a rate of 2 to 3 lb per mile, which, according to investigations conducted on this program, is sufficient. Guided by the above requirements, a dry-ice dispensing mechanism (discussed in Appendix C) suitable for use in the USD-1 was designed. A bench model of this dispenser was built and was shown to operate properly in laboratory tests.

The flight procedure for seeding whiteouts with the USD-1, depicted in Figure 7, should induce a cleared area over an airstrip that would last for about 1 hr. Note that the wind direction can shift within a 30° arc without seriously affecting the airstrip clearing. The drone should be launched about 30 min prior to the time during which clearing is desired, since it takes 25 to 30 min after seeding for clearing to progress to the point at which visual flight rule (VFR) landings can be made.

Maximum flight duration of the USD-1 is 30 min, according to the handbook. In a typical seeding mission, from 2 to 5 min was required to obtain radar contact with the drone, direct it to altitude, and orient it on the proper heading for the seeding run. Actual seeding required about 10 min, and returning the vehicle to proper position for recovery required an additional 5 min. Thus, the total seeding mission required approximately 20 min, leaving a safety factor of approximately 35% according to specified flight duration characteristics. Pertinent data concerning the USD-1 are summarized below:

1. The payload, normally listed as 65 lb, can be increased to 90 lb by removing the radar-reflector pods and replacing them with a DPN-62 radar beacon.
2. The extent to which payload may be jettisoned is limited to about 65 lb because of weight and balance considerations.

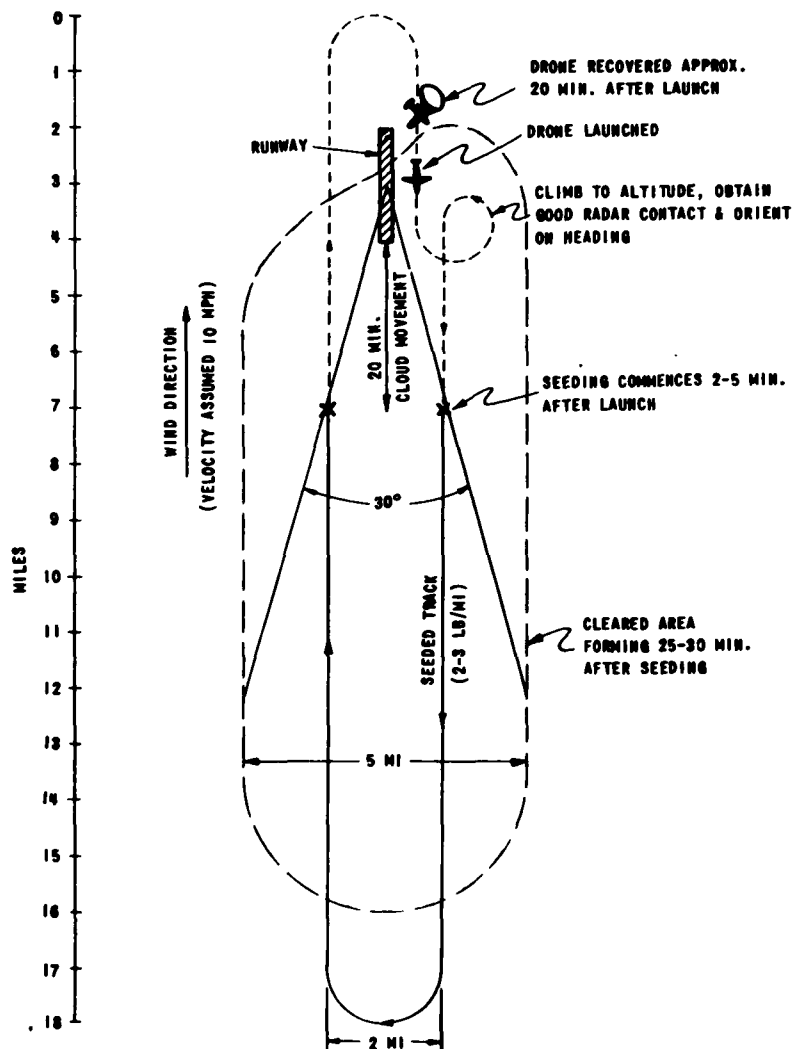


Figure 7. Seeding procedure for cloud dissipation over an airstrip.

3. The cargo compartment (Fig. 8) contains about 4000 in.³ of space, enough to handle a 65-lb load of dry-ice pellets plus the related dispensing machinery.

4. Maximum flight duration, according to representatives of the Radioplane Corp., manufacturers of the USD-1, is about 40 min; in the U. S. Army handbook, duration is specified to be 30 min, presumably to provide a safety factor.

5. The drone can be launched under limited visibility conditions (fog, night-time, etc.).

6. Electric power available for operation of the seeding mechanisms is 50 amp-min at 28 vdc. This is sufficient for the seeding mission.

7. There are three spare remote control channels available. One would probably be sufficient for the seeding operation.



Figure 8. Cargo compartment in USD-1.

8. Flight speed at sea level is 184 mph at 4100 rpm. The engine cannot be throttled down.

Putting aside certain logistic aspects of drone field operation in arctic environments, the use of drones as vehicles for cloud dissipation purposes is believed to be quite feasible. However, those logistic problems do exist, and, to date, they have made it appear advisable to drop drone work in favor of other approaches until U. S. Army field support for a drone test program is available.

DEVICES FOR SEEDING WHITEOUTS FROM THE GROUND

A brief investigation was made of the applicability of ordnance devices, such as small rockets and mortars, for seeding whiteouts. The procedure considered would require the rocket to carry a dry-ice payload to the proper altitude and to discharge it into the cloud below. The result would differ from that of airborne seeding in that dry ice would be discharged in discrete patches rather than a continuous line. Although the effectiveness of such a procedure has never been demonstrated experimentally in the field, there is no apparent reason why it cannot be made workable.

From investigations it has been concluded that an ideal ordnance device for use in whiteout seeding should possess the following characteristics:

1. The projectile should be lightweight, easy to transport, and simple to store.
2. The device should be simple to operate.
3. The payload compartment should accommodate about 1 lb of seeding material (dry ice) and should be easy to load.
4. The projectile should have a maximum altitude capability of at least 300 ft and possess a controllable burst-height feature.
5. The projectile should be completely frangible (or else parachuted to earth) so that falling pieces do not endanger personnel on the ground.

As part of the investigation, a trip was made to Picatinny Arsenal to talk to ordnance people about devices that might be used in seeding whiteouts. It was concluded that mortars are probably unacceptable because of the heavy pieces of shrapnel that must always fall back to earth and because of the high "g" forces associated with firing.

Simple rockets seem best suited to the purpose. Personnel of Picatinny's Rocket Development Section knew of no rocket meeting the ideals set forth above, but they felt that one could be developed at Picatinny.

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APPENDIX A.

THE EFFECT OF DRY-ICE PELLET VELOCITY ON THE GENERATION OF ICE CRYSTALS

SUMMARY

The influence of fall velocities of dry-ice pellets on the nucleation of slightly supercooled clouds is discussed and the conditions necessary for the production of ice crystals are examined. A theoretical argument is presented which suggests that, when cloud temperatures are warmer than about -5°C , the number of ice crystals produced by a pellet of dry ice moving at its terminal velocity decreases rapidly as the temperature approaches 0°C . In contrast to the pellet moving at terminal velocity, it is shown that the ice-crystal productivity of a slowly moving pellet remains high up to 0°C . An experimental verification of this predicted dependence upon pellet velocity is described, data are presented, and the implications of these findings for future seeding experiments are discussed.

INTRODUCTION

This investigation was carried out as part of an attempt to find a means of increasing the efficiency of the dry-ice, cloud-seeding process. The research on Project Whiteout included an investigation of the usefulness of limited-payload devices (such as drones, rockets and mortars) as vehicles for carrying dry-ice seeding material. In a search for means to improve seeding efficiency, it was found that dry-ice pellet velocity could have a strong effect on the number of ice crystals produced when supercooled clouds in the temperature range between 0°C and -7°C are seeded.

During the seeding of supercooled clouds and fogs, experimenters have observed that the chances of a positive result are significantly reduced when the cloud temperature is warmer than about -5°C . In a summary of approximately 100 dry-ice seeding experiments with cumulus clouds, Bowen (1952) concluded that in those cases where the cloud top temperature was -6°C or colder, virga and precipitation were produced in 100% of the cases, whereas at temperatures warmer than -6°C , the probability of success fell off progressively, tending to become zero at 0°C . Aufm Kampe, Kelly and Weickman (1957), on the basis of their dry-ice seeding experiments with supercooled stratus clouds, concluded that the temperature of the cloud deck must be colder than -4°C to achieve significant cloud modification.

There is evidence that this reduced effectiveness in seeding slightly supercooled clouds is due to an insufficient production of ice crystals by the falling pellets of dry ice. Evidence also indicates that dry-ice seeding at these temperatures might be effective if pellet velocity through the cloud is sufficiently slow. Other investigations have hinted at the apparently low ice-crystal productivity of dry ice at warmer supercooled cloud temperatures (Braham and Sievers, 1957; and Aufm Kampe et al., 1957). However, this phenomena has never been adequately explained, nor has the fact been revealed that ice-crystal productivity will remain high if the dry-ice pellet velocity is sufficiently slow.

THEORETICAL DISCUSSION

As a dry-ice pellet falls through a supercooled cloud, enormous concentrations of tiny ice embryos are created in the low-temperature, supersaturated boundary layer surrounding the pellet. These ice embryos can survive and grow only if they surpass a certain critical size which is determined by the prevailing temperature and humidity. The ice embryos created in the low-temperature boundary layer surrounding a falling dry-ice pellet remain in this environment for a short time only. As the dry-ice pellet falls through a region, the ice embryos are left in the pellet's wake where the temperature quickly returns to the ambient condition. For an ice embryo to exist and grow

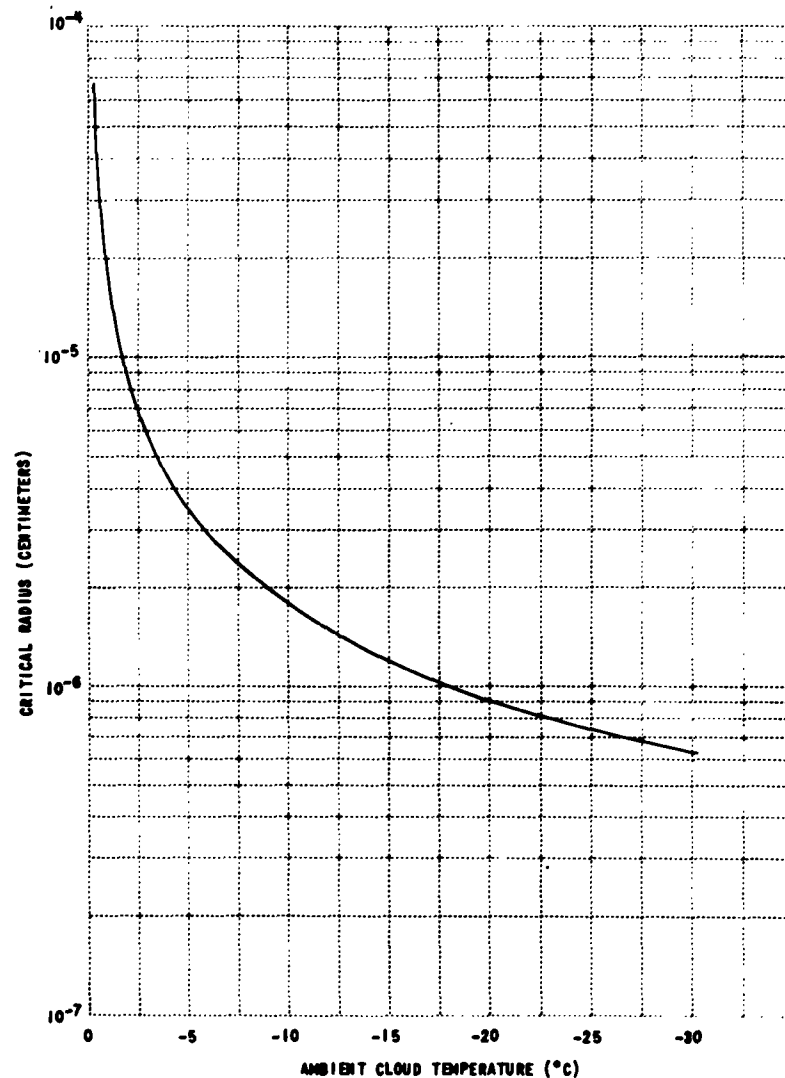


Figure A1. Critical radius for a stable ice embryo at ambient cloud conditions.

under ambient conditions in the cloud, it must have grown while in the low-temperature field of the passing dry-ice pellet to a size greater than the critical size appropriate to the ambient conditions. If an ice embryo does not reach this critical size before its environment returns to ambient conditions, the embryo will dissipate.

An expression for the critical radius of a spherical drop of pure liquid in the presence of its supersaturated vapor was deduced by Kelvin (1870) from a thermodynamic argument. Although Kelvin's equation is obviously only a crude approximation in the case of a crystal of nonspherical shape, where surface energy varies with crystallographic face, the relationship has been applied with some success to the problem of the homogeneous nucleation of supercooled water drops (Mason, 1952). Kelvin's equation,

$$r_c = \frac{2\sigma_s}{\rho_s R_w T \ln \frac{e}{e_\infty}} \quad (1)$$

was applied to estimate the critical radius r_c of an ice embryo under conditions of liquid water saturation. In the above equation σ_s is the specific surface free energy of the ice-vapor interface, ρ_s is the density of ice, R_w is the gas constant per gram of water vapor, T is the ambient temperature, e is the ambient vapor pressure, and e_∞ is the equilibrium vapor pressure at temperature T over a plane surface of ice.

The critical size for a stable ice embryo in a supercooled cloud was calculated from eq 1 for ambient temperatures ranging from -1C to -30C. The ambient vapor pressure e was taken to be the saturation vapor pressure over a plane surface of liquid water. Following McDonald (1953), the specific surface free energy of the ice-vapor interface was taken to be a constant of 96 ergs per cm^2 . In Figure A-1, the critical radius for an ice embryo under conditions of liquid water saturation is plotted against ambient temperature. One can see that the critical size which an ice embryo must reach in order to survive and grow at ambient conditions increases rapidly as the ambient temperature warms toward 0C.

Next, as an approximation to the rate of growth of an ice embryo while in the field of the dry-ice pellet, the rate of growth of a spherical ice-like aggregate was calculated.

When the radius r of a spherical aerosol droplet is sufficiently small, the expression for growth from the vapor phase (Fuchs, 1959) reduces to

$$\frac{dr}{dt} = \frac{\alpha \bar{C}}{4\rho_s} (\rho_{v\infty} - \rho_{vr}) \quad (2)$$

where α is the condensation coefficient (i. e., probability that a molecule striking the droplet is absorbed), \bar{C} is the mean speed of the vapor molecules, ρ_s is the density of the droplet, ρ_{vr} is the saturation vapor density at the surface of the droplet, and $\rho_{v\infty}$ is the vapor density in the undisturbed environment. The condition for validity of eq 2 requires that $r \ll \frac{L}{\alpha}$, where L is the mean free path of a vapor molecule. Under the conditions of extreme supersaturation, the expression of Burton, Cabrera and Frank (1951) for the growth of an imperfect crystal from the vapor phase reduces to the form of eq 2, indicating that that relation may also be applied to crystalline embryos under these conditions.

In evaporation experiments, Alty and MacKay (1935) found the condensation coefficient for water to be 0.04. Based on cloud chamber data for the growth rate of water droplets, Anderson (1957) estimates $\alpha \approx 0.05$. In the absence of similar information about the growth or evaporation of ice particles, it was assumed that $\alpha \approx 0.05$. This approximation is not without justification as there are indications (Jellinek, 1961) that ice in a saturated atmosphere may have a liquid-like surface layer many molecules thick.

Equation 2 was applied to estimate the minimum time required for an ice embryo, created in the supersaturated, low-temperature environment of the dry-ice pellet, to grow to the critical size necessary for survival at ambient cloud conditions. Since the mean free path of a water vapor molecule is approximately 10^{-5} cm, the condition $r \ll \frac{L}{\alpha} \approx 2 \times 10^{-4}$ cm is satisfied. The ambient vapor density $\rho_{v\infty}$ was taken to be the saturation vapor density over a plane surface of liquid water at the cloud temperature. The saturation vapor density ρ_{vr} at the surface of an ice embryo growing within the boundary layer of a falling dry-ice pellet is a function of the temperature and radius of curvature of the embryo. It was assumed that the ice embryos are created and grow initially in

those portions of the pellet boundary layer where the air is cooled below the apparent critical temperature (-40°C) for the spontaneous formation of ice crystals in a super-cooled cloud. Since the saturation vapor density over ice at these temperatures is much less than the ambient vapor density in the cloud, the expression $\rho_{v\infty} - \rho_{vr} = \rho_{v\infty}$ was assumed. Because this approximation does not apply in the final moment of growth when the temperature is returning to the ambient level, and may not be valid in the initial moments of growth when the radius of curvature of the embryo is very great, the time required for growth to critical size may be somewhat underestimated.

By integrating eq 2 and assuming that the initial radius of ice embryo is negligible when compared to the critical size r_c ,

$$t_{\min} \approx \frac{4 \rho_s r_c}{a \bar{C} \rho_{v\infty}} \quad (3)$$

an estimate of the minimum time required for growth to critical size was obtained. In Figure A-2, the minimum time required for an ice embryo to reach critical size is plotted against ambient cloud temperature. The mean speed of the water vapor molecules \bar{C} was taken to be $5.2 \times 10^4 \frac{\text{cm}}{\text{sec}}$, corresponding to -40°C . One sees that the minimum time which an ice embryo must remain in the boundary layer of a passing dry-ice pellet, in order to reach the critical size for stability at ambient conditions, increases rapidly as the cloud temperature approaches 0°C . At ambient temperatures colder than about -7°C , however, the minimum time required is roughly a constant 1 msec.

Next, the length of time that an ice embryo would remain in the field of influence of a falling dry-ice pellet was estimated, and this time was compared with the minimum time required for the growth of a stable ice embryo.

Over the range of dry-ice pellet sizes employed in typical seeding experiments, the terminal velocity of the pellet may be approximated by

$$V_t = CD^{\frac{1}{2}} \text{ cm/sec} \quad (4)$$

where D is the pellet diameter in centimeters, and the constant C is between 1×10^3 and 2×10^3 , depending upon pellet shape and density and air density.

A rough estimate of the length of time t that an ice embryo may remain in the field of a falling dry-ice pellet is given by

$$t \approx \frac{\pi}{2} \frac{D}{V_t} \quad (5)$$

Substituting in eq 5 for V_t ,

$$t \approx \frac{\pi}{2C} D^{\frac{1}{2}} \text{ sec} \quad (6)$$

was obtained, indicating that an ice embryo remains in the field of influence of a typical 1-cm pellet of dry-ice for a maximum of approximately 1 to 2 msec.

A comparison of the estimated minimum times required for the growth of a stable ice embryo (Figure A-2) with the preceding estimate of available growth time indicates that the time during which an ice embryo remains in the boundary layer of a falling dry-ice pellet may be of critical importance in determining the effectiveness of dry-ice seeding. As the cloud temperature becomes warmer than approximately -7°C , the time required for the growth of stable ice embryos exceeds the time available for this growth. Consequently, the number of stable ice crystals produced by a pellet of dry-ice falling at terminal velocity should decrease rapidly as the cloud temperature approaches 0°C . However, if the pellet moves slowly enough so that the ice embryos

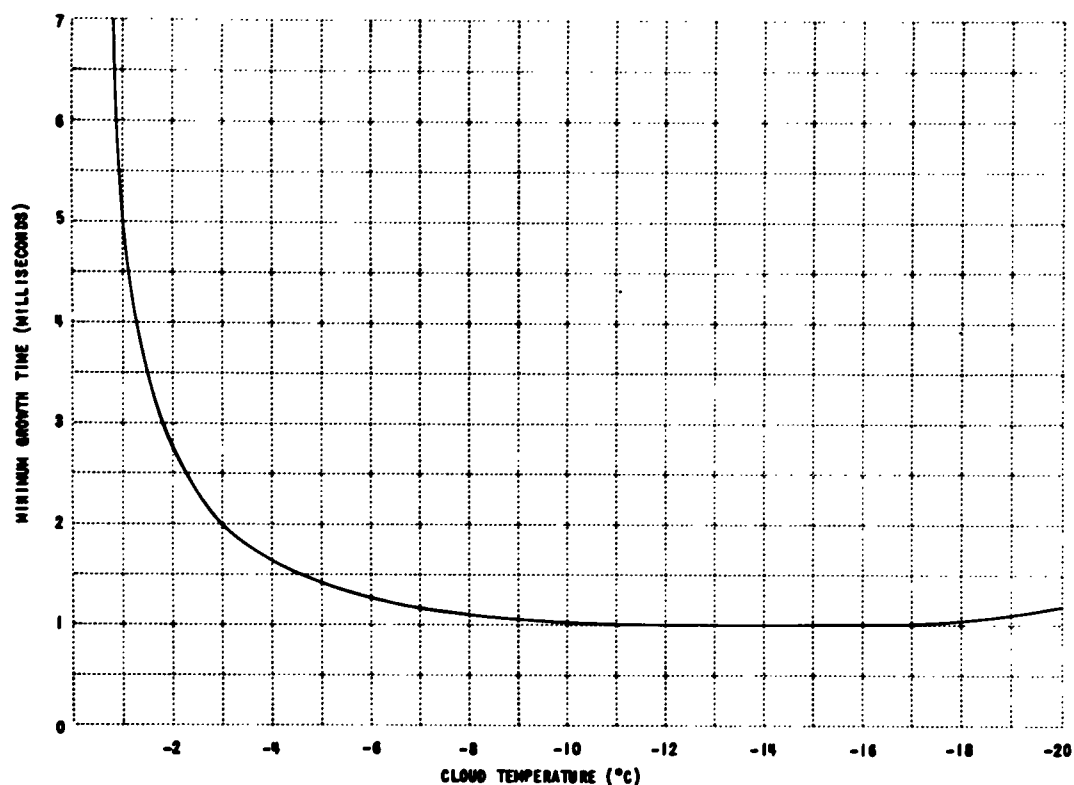


Figure A2. Minimum time required for an ice embryo to grow to critical size.

remain in its low-temperature environment for at least 10 to 20 msec, the ice crystal productivity should remain high even at temperatures close to 0°C.

While the approximations involved in the preceding discussion rendered the conclusions highly speculative in nature, the argument nevertheless served to indicate a fruitful direction for experimental investigation. It should be noted that no assumptions were made concerning the details of the nucleation processes by which the ice embryos are created. The argument is, therefore, equally applicable whether the ice embryos arise by direct sublimation from the vapor phase or by the freezing of tiny water droplets formed by spontaneous condensation. Any time lags inherent in the nucleation process will, of course, serve to reduce further the time available for the growth of stable ice embryos.

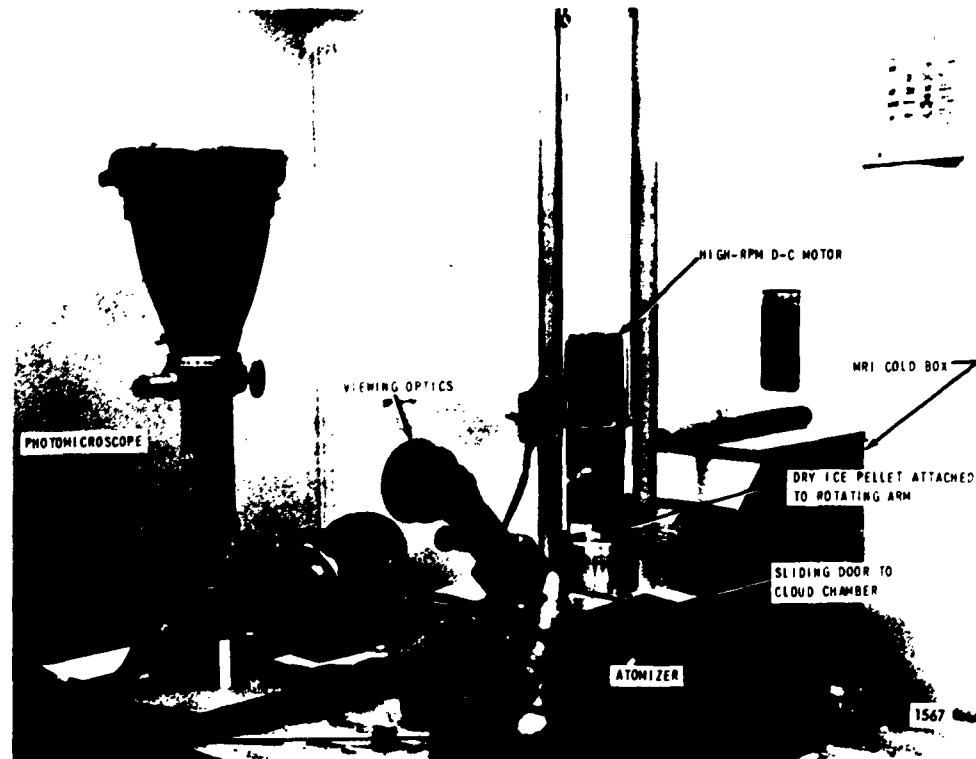


Figure A3. Experimental set-up.

THE EXPERIMENT

To determine the effect of pellet velocity upon the production of ice crystals, an MRI* portable cold box was altered to permit the seeding of supercooled clouds with dry-ice pellets moving at velocities comparable to the terminal velocities of falling pellets (Figure A3). A high-rpm, d-c motor was suspended on springs over an opening fitted with a sliding door in the top of the cloud chamber, and dry-ice pellets were attached to a rotating arm on the motor shaft.

In a typical seeding operation the following steps were taken: The temperature was measured by a thermometer inserted midway into the cloud chamber. A dense cloud was pumped into the chamber with a hand atomizer; turbulence created by the entering cloud served to insure a uniform temperature and a uniform distribution of cloud throughout the chamber. The motor was started and increased to the desired speed, whirling the dry-ice pellet in a horizontal circle about 1.5 in. in diam in a small entrance chamber just above the sliding door in the top of the cold box. (This entrance chamber was designed so that a minimum of warmer air, not more than 150 cm³, could enter the 2-liter cold chamber during the seeding operation. It also served to assure that small dry-ice particles, which tended to flake off the pellet when the motor was initially brought up to speed, did not enter the cloud chamber.) The sliding door was then opened, and the whirling pellet was quickly pushed about 2 in. down into the chamber. When pressure on the motor was released, the pellet was lifted clear of the cloud chamber, and the sliding door was closed.

* Meteorological Research Institute, Inc., Altadena, Cal.

Supercooled clouds over a range of temperatures from -1C to -24C were seeded in this manner, and the number of ice crystals produced was measured. Measurements were carried out at two motor speeds, approximately 8,000 rpm (pellet velocity 16 m/sec) and 400 rpm (pellet velocity 0.8 m/sec). The average pellet diameter was 1 cm, and the pellets remained in the supercooled cloud for approximately 1 sec.

When the density of the resulting ice cloud was below approximately 50 crystals per cm^3 , the number of crystals was estimated from visual observation of the ice cloud through the calibrated optical system of the cold box. For higher cloud densities the ice cloud was continuously humidified until all crystals had grown to a size sufficient to precipitate them to the bottom of the chamber. A glass slide, which had been placed on the bottom of the chamber, was removed and photomicrographs were immediately taken. By a count of the number of ice crystals in the resulting photomicrograph, the total number of ice crystals in the chamber could be estimated. (Deposition of ice crystals on the side walls of the chamber was found to be insignificant.)

In Figure A4, the total numbers of ice crystals produced at two different pellet velocities are plotted against the temperature of the supercooled cloud. Above approximately -7C, the number of ice crystals produced by the pellet moving at 16 m/sec decreased rapidly as the cloud temperature approached 0C. Between -7C and -2C, the ice-crystal production of the faster moving pellet decreased by a factor of 10^4 . From eq 5 the time available for the growth of a stable ice embryo in this case was approximately 1 msec, a typical value for a 1-cm pellet falling at terminal velocity. In contrast, the number of ice crystals produced by the slowly moving pellet decreased only slightly at the warmer temperatures. At a pellet velocity of 0.8 m/sec, the ice embryos remain in the low-temperature environment of the pellet for about 20 msec. The effect of pellet velocity upon ice-crystal production at the warmer temperatures is even more apparent, when one considers that the pellet moving at terminal velocity sublimed more rapidly and cooled more cloud in the 1-sec exposure time than did the slowly moving pellet.

It should be noted that the production of ice crystals at the colder temperatures would correspond to a yield of approximately 10^{10} ice crystals per gram of dry-ice dissipated, far below Langmuir's (1948) prediction of 10^{17} ice crystals per gram. However, since approximately 4×10^7 ice crystals were produced within the cold chamber in a typical seeding run at the colder temperatures, the ice-cloud contained at least 2×10^4 ice crystals per cm^3 . It is possible that this may represent an upper limit to the ice-crystal concentration that can exist for any length of time in the 2-liter cold chamber. Even though the ice cloud was continuously supplied with moisture, competition for moisture by the ice crystals may have resulted in such a limit. For this reason it would be desirable to repeat the experiment in a larger cold chamber.

SUMMARY AND CONCLUSIONS

It was found that the number of ice crystals produced by a dry-ice pellet moving through a supercooled cloud at terminal velocity drops off sharply when the cloud temperature is warmer than about -7C. It is hypothesized that at these temperatures the embryonic ice crystals do not remain in the field of influence of the falling dry-ice pellet long enough to reach the critical size necessary for survival and growth at the ambient cloud conditions. It was shown that the ice-crystal productivity of a slowly moving pellet, where the ice embryos reach critical size before leaving the low-temperature, extremely supersaturated environment of the dry-ice pellet, remains high up to 0C.

These findings indicate that a "stationary" seeding technique, where the embryonic ice crystals remain in a low-temperature, highly supersaturated environment for at least 10 to 20 msec, may permit modification of supercooled clouds and fogs in the -5C to 0C temperature range where previous attempts have not been effective. Seeding techniques such as the tethered-blimp method (Justo and Rogers, 1960) should be investigated for potential application at these temperatures. Similarly, the use of low-density, high-drag flakes or pellets of dry-ice may permit an extension of conventional aircraft seeding techniques to warmer temperatures.

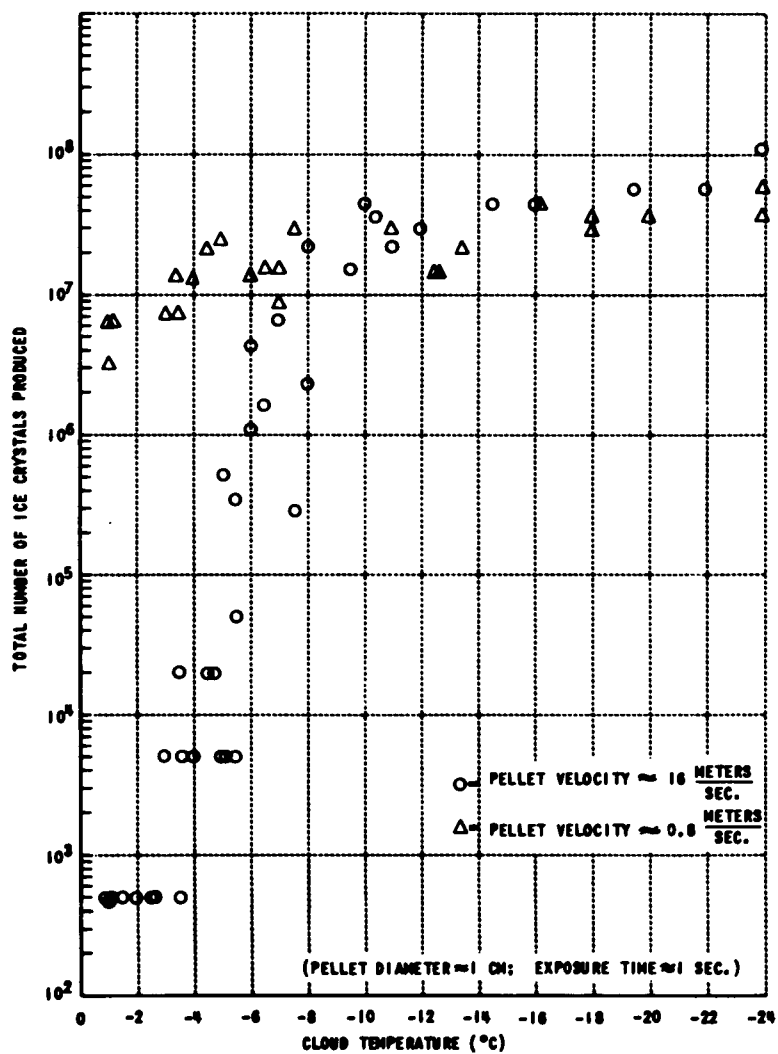


Figure A4. Effect of dry-ice pellet velocity on ice-crystal productivity.

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APPENDIX B.

DISTANCE OF FALL OF DRY-ICE PELLETS

SUMMARY

The time required for the complete sublimation of dry-ice pellets falling at their terminal velocities was measured as a function of pellet size and ambient air temperature. From this information, fall distances of dry-ice pellets were calculated. The results are compared with those of previous investigators.

TECHNICAL DISCUSSION

In cloud-seeding operations the accurate predictions of the distance that dry-ice pellets will fall is essential if the dry ice is to be used efficiently. From a knowledge of fall distance as a function of pellet size and air temperature, an optimum pellet size may be selected for a given mission.

Langmuir (1947) computed the distances that dry-ice pellets of different sizes should fall through the atmosphere at -20°C . Vonnegut (1949), by suspending pellets of dry-ice in a stream of air moving upwards through a glass tube, determined the fall distances of small pellets at room temperature and obtained results which are lower than Langmuir's theoretical values by a factor of 2. Although Squires and Smith (1949) reported experimental verification of Langmuir's values, it was only within a factor of 2. Therefore, in an effort to establish definitely the distance of fall of dry-ice pellets as a function of pellet size and air temperature, an experimental determination of their fall characteristics was carried out.

A small, vertical wind-tunnel approximately 4 ft long was constructed with acetate sheet. The tunnel diameter varied continuously from 1.25 in. at the bottom to 2.5 in. at the top, creating a four-to-one variation in flow velocity between the bottom and top of the tunnel. A fine-wire screen was fitted over the bottom of the tunnel to reduce large-scale turbulence in the test section. A blower was connected to the bottom of the tunnel, and blower speed was controlled by means of a variac. The entire apparatus (Figure B1) was operated in a cold room where an adequate supply of cold air was available and temperatures could be maintained to within 1°C .

Under the influence of the vertical-velocity gradient in the tunnel (due to variation of diameter with height), the subliming dry-ice pellets were continuously suspended at a point in the flow where the gravitational force on the pellet was just balanced by the aerodynamic forces. Thus, it was possible to subject each subliming dry-ice pellet to flow conditions similar to those it would experience in falling through the atmosphere.

Measurements were made of the time required for the complete sublimation of a pellet, of a given initial mass, while suspended at terminal velocity in air of known temperature. The times of fall at various temperatures* were measured for a number of dry-ice pellets of irregular shape, ranging in initial mass from 0.3 g to 7.3 g. In Figure B2 the times of fall are plotted against initial pellet mass. Much of the scatter in the experimental data results from variations in shape, hence in aerodynamic characteristics, among pellets of the same initial weight.

From a least squares fit of the 25°C data (see Figure B2), the time of fall of the dry-ice pellets is given by

$$t = 153M^{0.42} \quad (1)$$

where t is the time of fall in seconds and M is the initial mass of the pellet in grams. The measured average density of the dry ice was $1.4 \frac{\text{g}}{\text{cm}^3}$; therefore, the dependence of time of fall upon the initial diameter of an equivalent spherical pellet is

$$t = 134D_i^{1.26} \quad (2)$$

* It should be noted that temperatures were measured in the tunnel near the point where the pellet was suspended. This was necessary since the air temperature was always higher at a point after the blower.

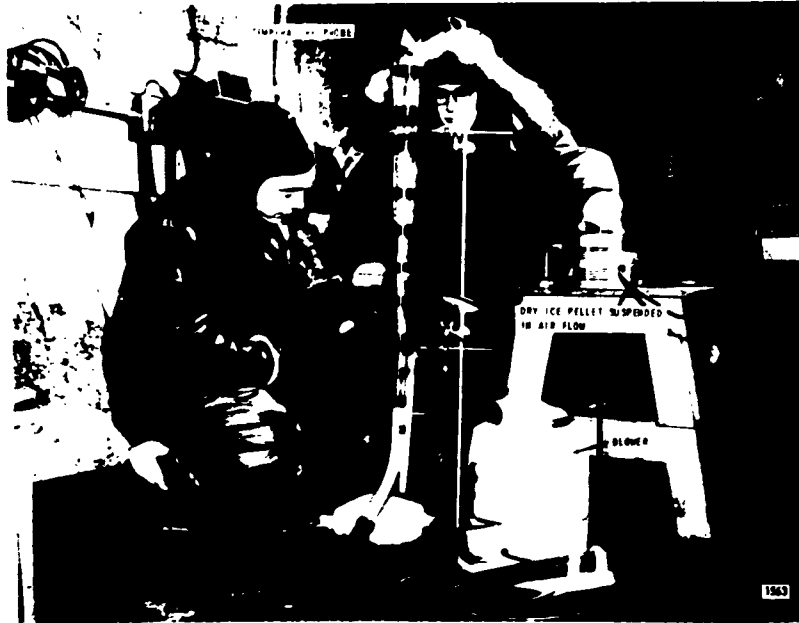


Figure B1. Experimental set-up for determining fall distances of dry-ice pellets.

where D_i is the initial diameter of the pellet in centimeters. Differentiating eq 2 with respect to time, and introducing a minus sign (so that the diameter decreases with time), an expression for the time rate of change of pellet diameter is obtained as follows:

$$\frac{dD}{dt} = -5.92 \times 10^{-3} D^{-0.26}, \quad (3)$$

where D is the pellet diameter in centimeters.

Denoting the height of a falling pellet by H , the terminal velocity of the pellet is $V_t = \frac{-dH}{dt}$, and the rate of change of pellet diameter with height is given by

$$\frac{dD}{dH} = \frac{dD}{dt} \frac{dt}{dH} = -\frac{dD}{dt} \frac{1}{V_t}. \quad (4)$$

Over the range of pellet sizes under consideration, the terminal velocity of a spherical pellet may be approximated by

$$V_t = 2.0 \times 10^3 D^{\frac{1}{2}} \text{ cm/sec.} \quad (5)$$

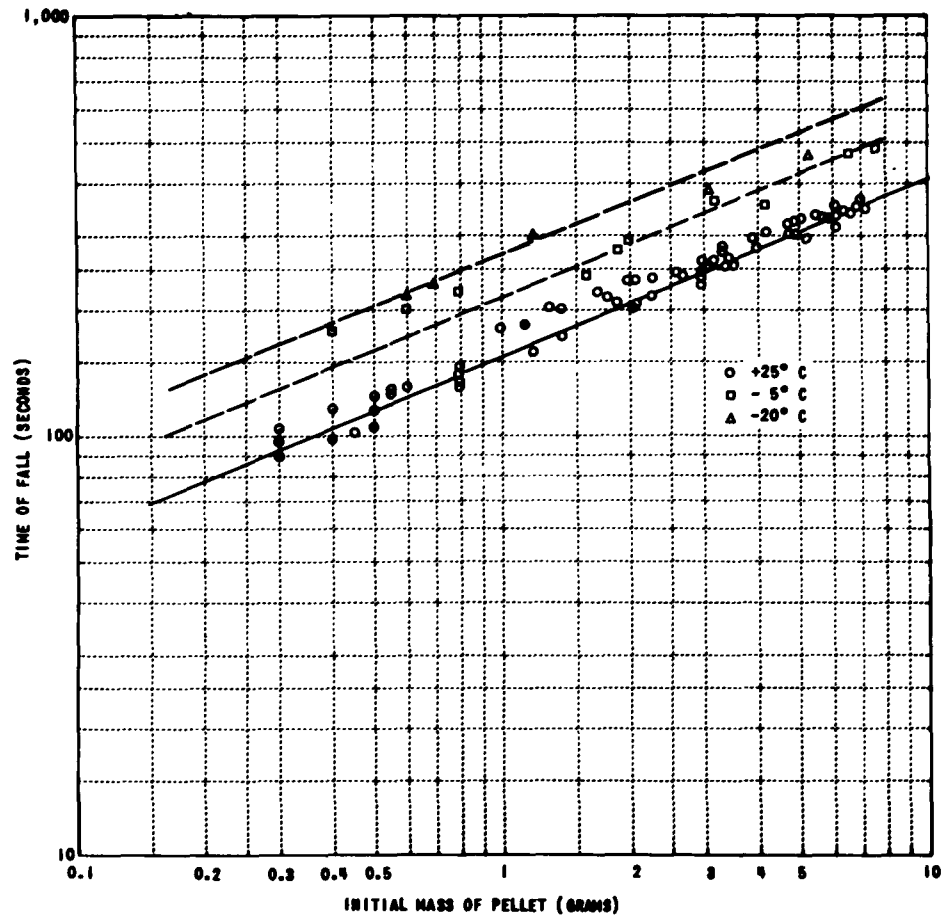


Figure B2. Time of fall of dry-ice pellets.

By substitution in eq 4, the variation in the diameter of a falling dry-ice pellet with height H is

$$\frac{dD}{dH} = 3.0 \times 10^{-4} D^{-.76} \quad (6)$$

where the height H is in meters. Integrating eq 6 an expression for the total fall distance of a dry-ice pellet at +25C is obtained:

$$\Delta H = 1.9 \times 10^3 D_1^{1.76} \text{ meters} \quad (7)$$

where the initial pellet diameter D_1 is in centimeters. Near the end of the fall when the pellet diameter and velocity become small, eq 5 will cease to be a good approximation for the terminal velocity. The distance covered in this final period, however, will be very small, and the use of eq 5 will introduce no significant error in the fall distances of pellets in the size range encountered in typical seeding experiments. Based on eq 7, fall distance is plotted against initial pellet diameter and mass in Figure B3.

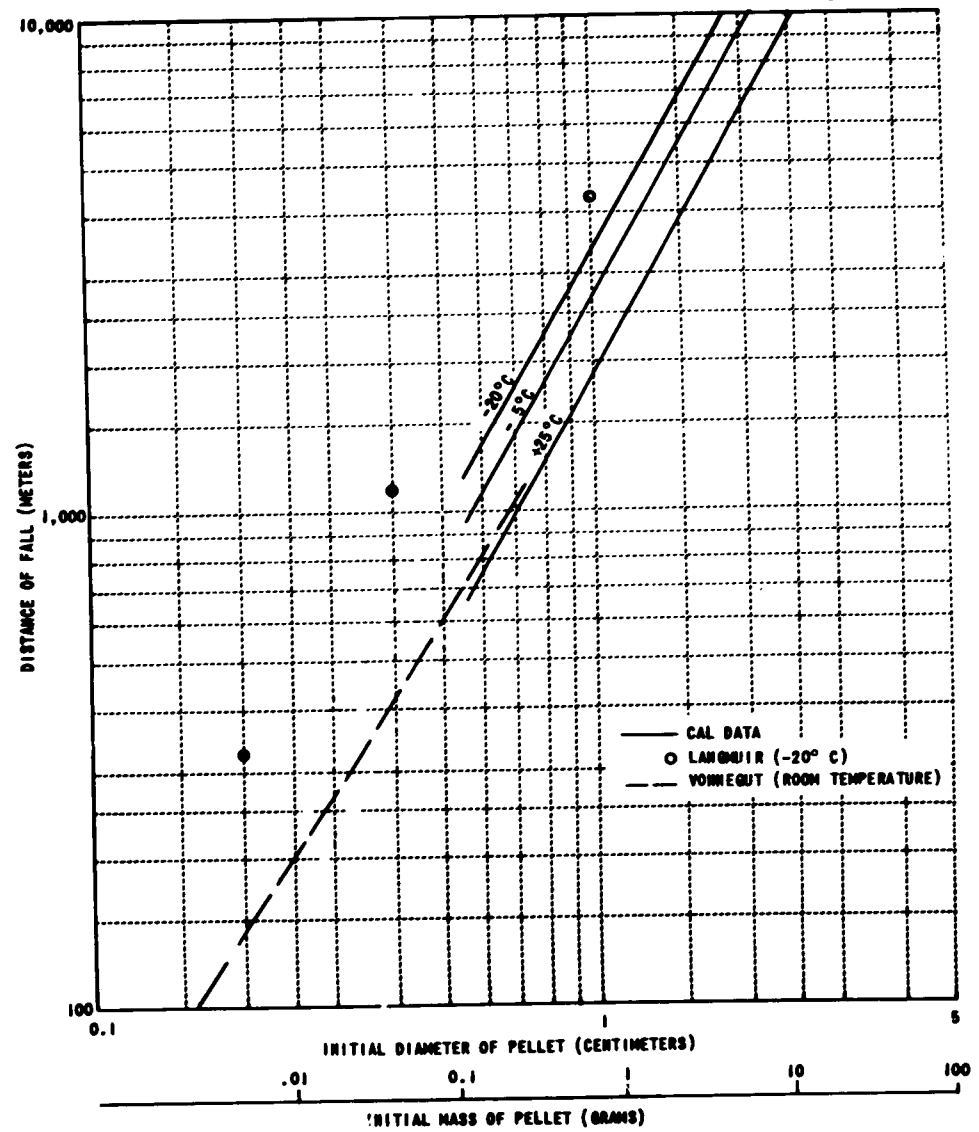


Figure B3. Fall distances of dry-ice pellets.

The curves through the data points taken at -5°C and -20°C could have been obtained in a manner similar to that described above; however, since the data at these colder temperatures were not so plentiful as those for $+25^{\circ}\text{C}$, a different approach was used. It was noted that the time of fall should be inversely proportional to the difference between ambient air temperature and the surface temperature of the dry-ice pellet, and that the slope of curves through the -5°C and -20°C points would be the same as that for the 25°C points.

The dependence of time of fall on temperature can be seen when the equation for the transport of heat to the falling dry-ice pellet is examined:

$$L_s \rho \frac{\pi}{2} D^2 \frac{dD}{dt} = h \pi D^2 (T_s - T_a) \quad (8)$$

where L_s is the heat of sublimation of dry ice, ρ is the density of dry ice, \underline{D} is the pellet diameter, h is the average heat transfer coefficient in the pellet boundary layer, T_a is the ambient air temperature, and T_s is the surface temperature of the dry-ice pellet. Solving eq 8 for the time rate of change of pellet diameter,

$$\frac{dD}{dt} = \frac{2h}{\rho L_s} (T_s - T_a) \quad (9)$$

is obtained. Since the average heat transfer coefficient h is only slightly dependent on the ambient air temperature, one can see from eq 9 that the time of fall should be inversely proportional to the difference between the surface temperature of the dry-ice pellet and the ambient air temperature.

To show that the slope of the curve does not vary with temperature, the heat transfer coefficient h is examined, which can be represented in the form

$$h = \frac{cK}{D} \left(\frac{DV_t}{\nu} \right)^m \quad (10)$$

where K is the thermal conductivity in the pellet boundary layer, V_t is the terminal velocity of the pellet (which from eq 5 is $2 \times 10^3 D^{\frac{1}{2}}$ cm/sec), ν is the kinematic viscosity in the pellet boundary layer, c and m are empirically determined constants, and \underline{D} is the diameter of the pellet. Substituting in eq 9,

$$\frac{dD}{dt} = \frac{2cK(2 \times 10^3)^m (T_s - T_a)}{\rho L_s \nu^m} D^{\frac{1}{2}m-1} \quad (11)$$

is obtained, which is equivalent to eq 3. The slope of this curve, when $\log \underline{D}$ is plotted against $\log t$ as in Figure B2, is determined entirely by the exponent of \underline{D} and is, therefore, a constant independent of temperature.

Thus, the curves through the -5C and -20C points in Figure B2 were obtained by multiplying the right side of eq 1 by the appropriate constant as follows:

$$t = 153M^{0.42} \left(\frac{T_s - 25C}{T_s - T_a} \right). \quad (12)$$

Taking into account the scatter in the data, this predicted temperature dependence appears to be a useful approximation. Working from eq 12, the equations for fall distance at -5C and -20C were obtained in a manner similar to that described for the data based on 25C.

In Figure B3 the distance of fall is plotted against initial mass of the dry-ice pellet for ambient temperatures of +25C, -5C and -20C. The theoretical values of Langmuir for -20C and the room temperature data of Vonnegut are included for comparison. While there is close agreement with Vonnegut's results for the larger pellet diameters, the theoretical values of Langmuir for -20C seem somewhat high. It is not surprising that the slope of the curves are different from Vonnegut's. The data was taken with larger pellets than those used by Vonnegut and, as has already been noted, the equations are not expected to hold for very small pellet sizes.

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APPENDIX C.

DRY-ICE DISPENSING MECHANISM

In the whiteout-seeding experiments cakes of dry ice had been fed into an ice crusher, which produced pellets of varying sizes and discharged them into the cloud. As discussed under "Improving the Efficiency of Dry-ice Seeding," investigations showed that the ice-crushing method of seeding was inefficient. For this reason, instead of carrying an ice crusher, it is preferable for a drone to carry pellets of dry ice which would be discharged from a hopper and dispensing mechanism designed especially for use in drones.

Before design of the dry-ice hopper was begun, the storage properties of dry-ice pellets had to be ascertained, for it was necessary to ensure that the pellets would not adhere to each other and thus possibly clog the dispensing mechanism. Several batches of chopped-up dry ice were stored for varying lengths of time under different conditions of temperature and humidity. In the case of the pellets stored in open containers, there was a tendency for water vapor to condense and to freeze on the surface of the pellets, causing them to stick together. However, when the dry ice was kept in closed containers, there was no tendency for sticking to occur; in fact, one batch was kept for more than 24 hr in a simple Sears-Roebuck picnic chest located in a warm, humid room, and the dry-ice pellets did not adhere to each other. Thus, it was determined that preformed dry-ice pellets could be stored without clumping. During the 24-hr storage — a long period in the context of the research aims — about 50% of the dry ice had sublimed, thus leaving pellets of about one-half their original mass.

The rate at which the dispenser must deliver dry ice is determined by the airspeed of the seeding vehicle and the seeding rate to be employed. Under typical whiteout conditions a seeding rate of about 2 lb per mile should be sufficient, if the proper size of dry-ice pellets is used. The airspeed of the USD-1 is 180 mph; therefore, the output of its dry-ice dispenser has to be at least 6 lb/min.

So that it could be useful in a number of different aircraft under a wide variety of conditions, it was decided to design and build a dispenser with a variable output rate. The dispenser, shown in Figure C1, consists of a 3-in. -diam worm gear with a 1-in. -diam shaft and a 1-in. pitch. Figure C2 depicts the proposed installation in the USD-1. The output of this experimental model can be varied either to increase or decrease the seeding rate so that the estimates of required seeding rates can be checked in future seeding experiments.

The output of the dry-ice pellet dispenser was checked in the laboratory with pellets of commercially produced dry ice of density about 1.5 g/cm^3 (the density of dry ice varies depending on how it is made). The dry ice was crushed and sorted so that pellets of about 0.5-in. diam were used for the tests. The output was found to be 8 lb/min when the worm gear was turning at 60 rpm, and 15 lb/min when turning at 120 rpm. However, it must be realized that these rates will vary depending upon the density and size distribution of the pellets used. Therefore, it is important that the dispenser be calibrated for the type of pellets to be used in a given experiment.

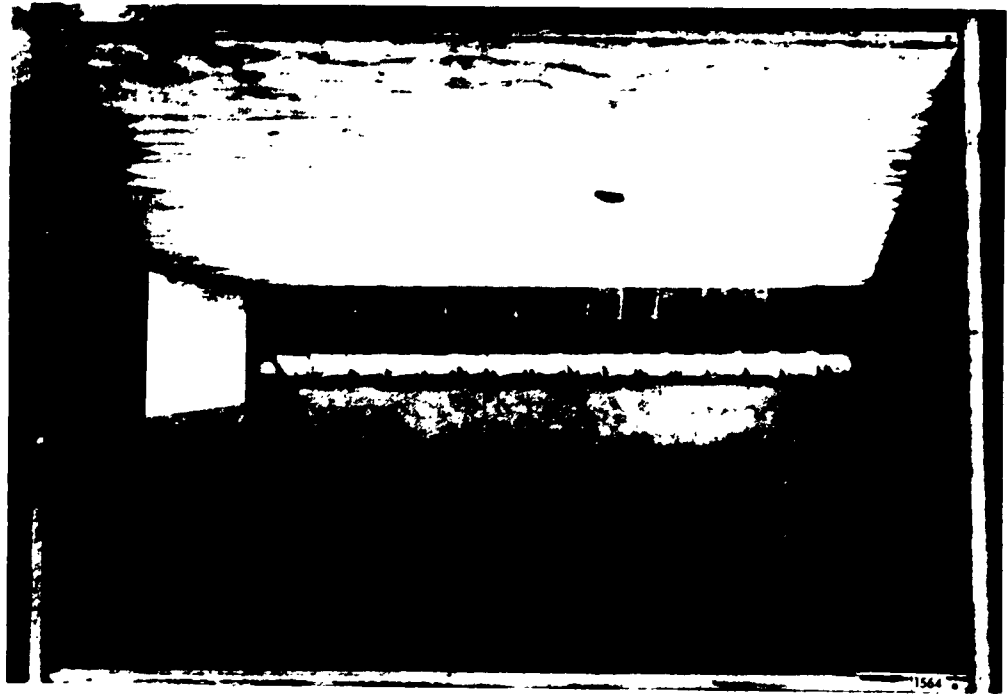


Figure C1. Mechanism for dispensing dry-ice pellets at controlled rates.

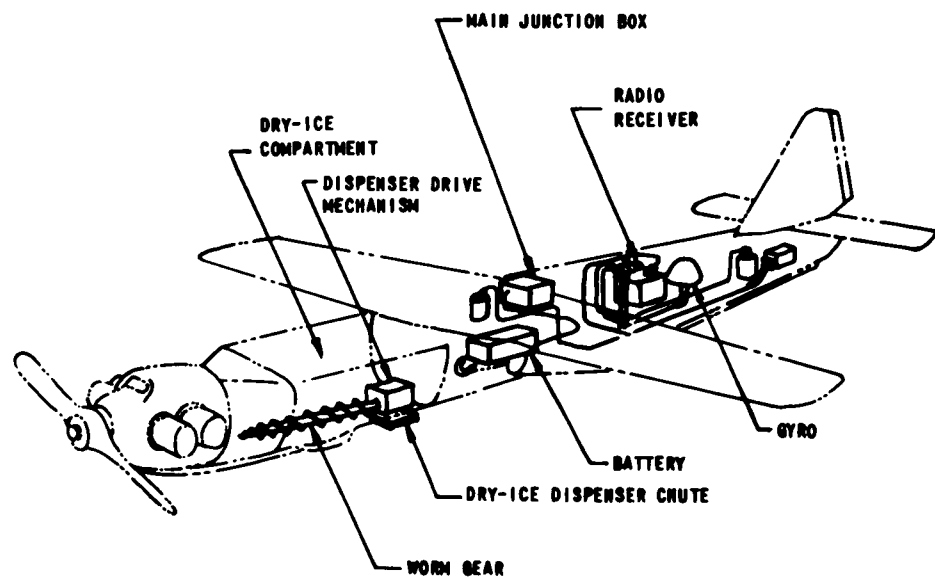


Figure C2. Dry-ice pellet dispenser showing proposed installation in the USD-1.

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